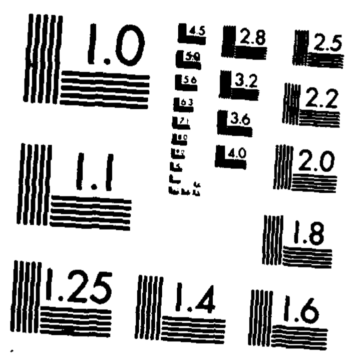
AD-A173 712 LIGHTNING WARNING AND PROTECTION FOR DNA HIGH EXPLOSIVE 1/1
TEST-BED(U) MISSION RESEARCH CORP ALBUQUERQUE NM
W RISON AUG 86 AMRC-R-794 AFWL-TN-86-14
UNCLASSIFIED F29601-85-C-0009 F/G 14/2 NL



ICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

AFWL-TN-86-14

AFWL-TN-86-14

3

LIGHTNING WARNING AND PROTECTION FOR DNA HIGH EXPLOSIVE TEST-BED

W. Rison

Mission Research Corporation
1720 Randolph Road, S.E.
Albuquerque, NM 87106

August 1986

Final Report

Approved for public release; distribution unlimited.

AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117-6008

This final report was prepared by the Mission Research Corporation, Albuquerque, New Mexico, under Contract F29601-85-C-0009, Job Order 672A0911 with the Air Force Weapons Laboratory, Kirtland Air Force Base, New Mexico. Mr David H. Hilland (NTA) was the Laboratory Project Officer-in-Charge.

This technical report has been reviewed and is approved for publication.

DAVID H. HILLAND
Project Officer

FOR THE COMMANDER

RICHARD A. PAULSEN
Capt, USAF
Chief, Technology Branch

PHILIP J. MESSURI
Major, USAF
Chief, Aircraft and Missiles Division

UNCLASSIFIED
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

1a. REPORT SECURITY CLASSIFICATION
Unclassified

1b. RESTRICTIVE MARKINGS
A173912

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION / DOWNGRADING SCHEDULE

3. DISTRIBUTION / AVAILABILITY OF REPORT
Approved for public release; distribution unlimited.

4. PERFORMING ORGANIZATION REPORT NUMBER(S)
AMRC-R-794; MBES-2-NMTECH-037

5. MONITORING ORGANIZATION REPORT NUMBER(S)
AFWL-TN-86-14

6a. NAME OF PERFORMING ORGANIZATION
Mission Research Corporation

6b. OFFICE SYMBOL *(If applicable)*

7a. NAME OF MONITORING ORGANIZATION
Air Force Weapons Laboratory

6c. ADDRESS *(City, State, and ZIP Code)*
1720 Randolph Road, SE
Albuquerque, NM 87106

7b. ADDRESS *(City, State, and ZIP Code)*
Kirtland AFB, NM 87117-6008

8a. NAME OF FUNDING / SPONSORING ORGANIZATION

8b. OFFICE SYMBOL *(If applicable)*

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
F29601-85-C-0009

8c. ADDRESS *(City, State, and ZIP Code)*

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.
64312F	672A	09	11

11. TITLE *(Include Security Classification)*
LIGHTNING WARNING AND PROTECTION FOR DNA HIGH EXPLOSIVE TEST-BED

12. PERSONAL AUTHOR(S)
W. Rison

13a. TYPE OF REPORT	13b. TIME COVERED	14. DATE OF REPORT (Year, Month, Day)	15. PAGE COUNT
Final	FROM May 85 TO Nov 85	1986 August	42

16. SUPPLEMENTARY NOTATION

17. COSATI CODES

FIELD	GROUP	SUB-GROUP
04	01	

18. SUBJECT TERMS *(Continue on reverse if necessary and identify by block number)*
Lightning
Lightning Protection

19. ABSTRACT *(Continue on reverse if necessary and identify by block number)*

Langmuir Laboratory, a scientific laboratory dedicated to the study of thunderstorms, contains an elaborate collection of electronic equipment which must function during severe thunderstorms. Over the years, electronic hardening devices have been installed so that increasingly sophisticated electronic equipment can be safely operated in this very hostile environment. DNA's High-Explosive Test-Bed represents a large investment in electronic sensors and high explosives which must remain safe during the frequent thunderstorms of southern New Mexico. This report details the hardening practices and procedures necessary to protect the electronics, high explosives, and personnel at the High-Explosive Test-Bed. In particular, a warning system is described that will sound an alarm if an electrical storm approaches.

20. DISTRIBUTION / AVAILABILITY OF ABSTRACT
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS

21. ABSTRACT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
David H. Hilland

22b. TELEPHONE *(Include Area Code)*
(505) 844-9758

22c. OFFICE SYMBOL
NTA

DD FORM 1473, 84 MAR — 83 APR edition may be used until exhausted. All other editions are obsolete.

SECURITY CLASSIFICATION OF THIS PAGE
UNCLASSIFIED

ACKNOWLEDGMENTS

The author wishes to thank Dr. C. B. Moore for the informative technical discussions during the program.

CONTENTS

ILLUSTRATIONS

1. INTRODUCTION

As part of this subtask, New Mexico Institute of Mining and Technology (New Mexico Tech), under subcontract to Mission Research Corporation, was to study ways to reduce lightning-caused damage at the Permanent High Explosives Test Site (PHETS) at White Sands Missile Range, New Mexico. This reports summarizes recommendations of lightning protection methods for PHETS.

The PHETS site, located in south-central New Mexico, is in a region which receives many thunderstorms during a typical year. In the past, the lightning which accompanies these thunderstorms has damaged sensors, cables, and instruments at the site, causing delays in tests and costs to replace the damaged items.

Langmuir Laboratory (Langmuir), operated by New Mexico Tech and located in the Magdelana Mountains in south-central New Mexico, receives an average of 80 thunderstorms during a summer. At Langmuir, cable runs of up to 2 km connect sensors to recording instruments. Over the years lightning protection measures have been implemented to allow operation of the Laboratory during thunderstorms with little lightning-related damage. Before these protection measures were implemented, a typical storm would knock out 20 to 40 sensors. After implementation little damage was suffered from storms, with perhaps a sensor or recorder knocked out every two weeks. Repair usually consisted of replacing the input buffer or transient overflow device. Recommendations for reduction of lightning-caused damage for the PHETS site were made from the experience gained.

A report by R. H. Golde on lightning protection is found in Reference 1, and lightning protection considerations for munitions manufacturing and handling is discussed by Moore et al. in Reference 2.

A good source of information on grounding techniques, which can be effective in reducing damage caused by lightning-induced effects, is found in Reference 3. Lightning protection is specifically discussed in this report for the PHETS site, taking into consideration its geographical location and the types of operations conducted there. Those aspects of thunderstorms which are useful in warning of an impending lightning hazard are looked at along with those which cause damage. Protection recommendations are made in three areas: protection of instrumentation, protection of the high explosive, and protection of personnel.

2. THE THUNDERSTORM

Lightning is produced by the electrical breakdown of air in regions of strong electric fields associated with charges in thunderclouds. The processes by which clouds become charged is the subject of considerable debate but are not of concern here. Interest here is in the characteristics of a thunderstorm which can be used to give warning of a lightning potential.

The charge distribution in a cloud of a typical summer thunderstorm is shown in Fig. 1. Large positive, P, and negative, N, charge centers of typically 40 C are separated by about 5 km, with the positive charge near the cloud top and the negative charge near the bottom. A small positive space charge, p, created from positive ions produced by point discharge at the earth's surface, is in the subcloud region below the negative charge center. These charges, together with their image charges below the ground plane, give rise to electric fields at the ground. The magnitudes of these fields, as a function of distance from the cloud, are shown in Fig. 2.

The electric fields on the ground below a thundercloud are much stronger than the fields on a clear, fine-weather day. While fine-weather fields are typically -100 V/m, the foul-weather fields under a thundercloud are in the range of +5 to +15 kV/m.

A lightning discharge will neutralize some of the charge in the cloud. An intracloud discharge will neutralize both the P and the N charges, as well as their image charges below the ground plane. A cloud-to-ground discharge will neutralize the N charge and its image. These discharges will produce rapid field changes which can be measured from large distances.

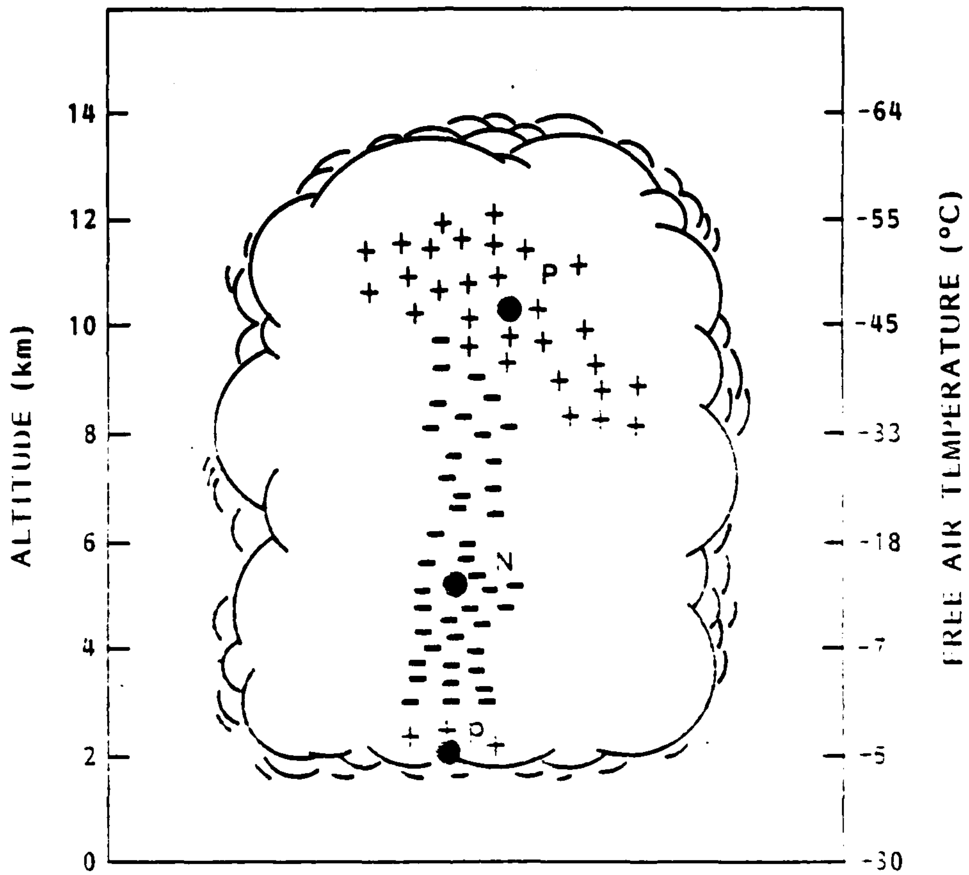


Figure 1. Probable distribution of the thundercloud charges, P, N, and p. The solid black bullets indicate locations of effective point charges; typically, P = +40 C, N = -40 C, and p = +10 C, and give observed electric field intensity in the vicinity of the thundercloud. (Ref. 4, p. 3.)

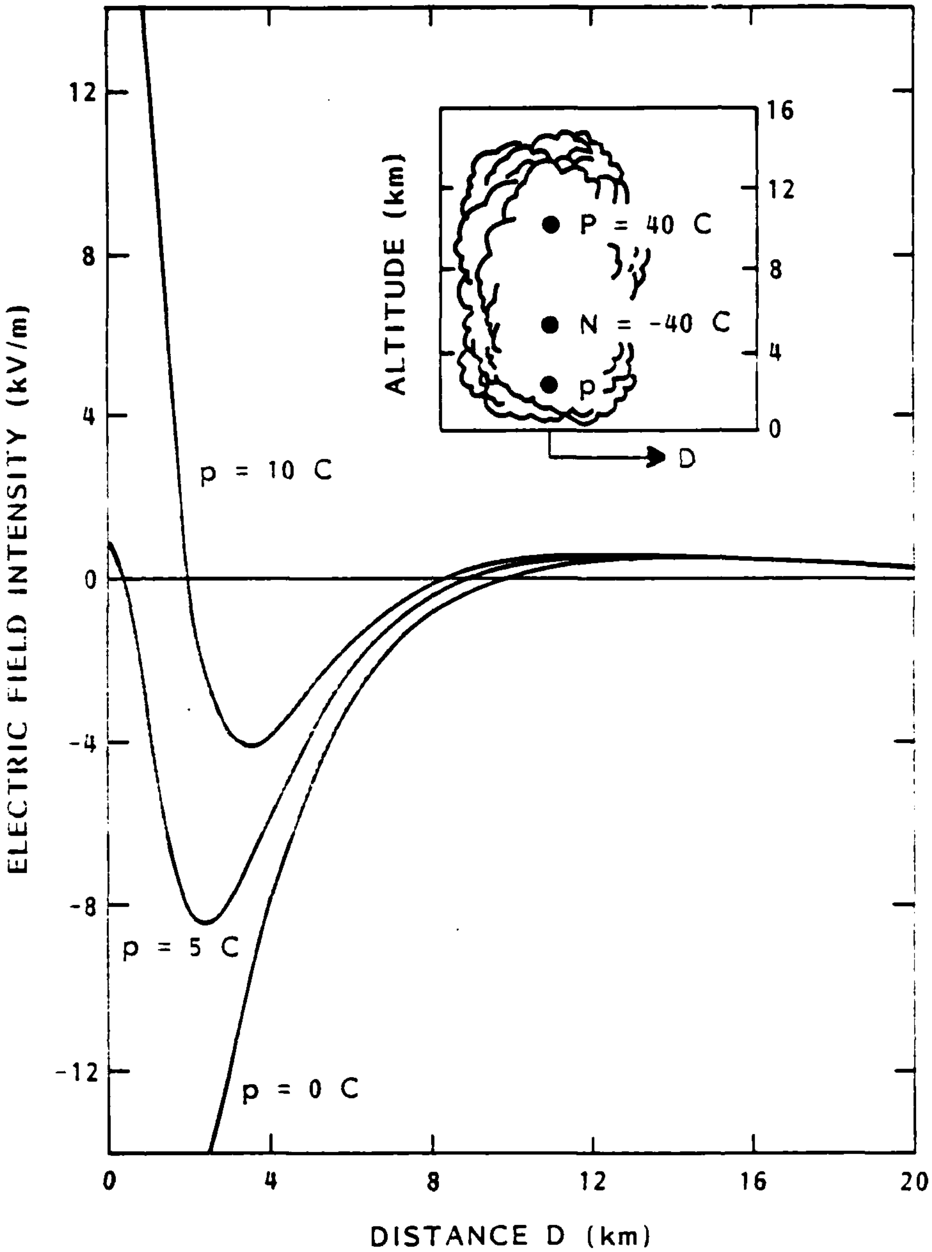
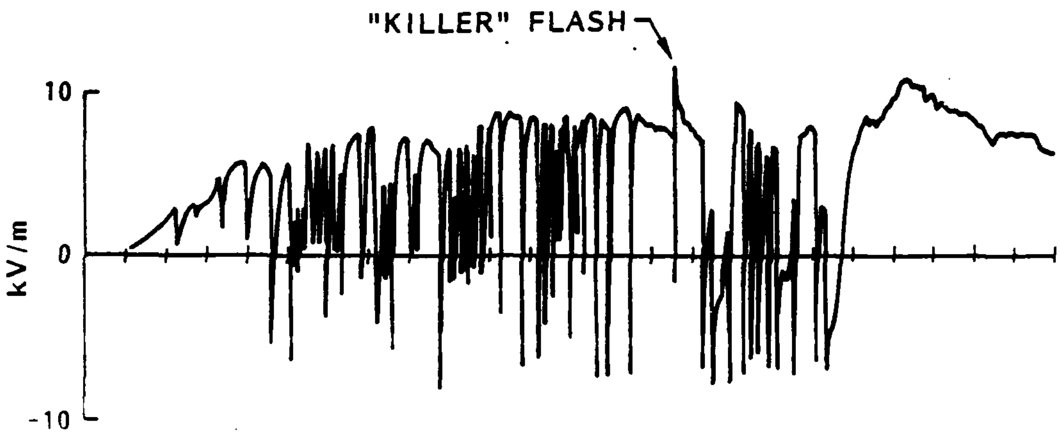


Figure 2. Electric field intensity at the ground versus distance for P = 40 C at 10-km height, N = -40 C at 5-km height, and three values of p at 2-km height. Note that Uman's convention (Ref. 4, p. 51) for electric field polarity is opposite that used elsewhere in this report.

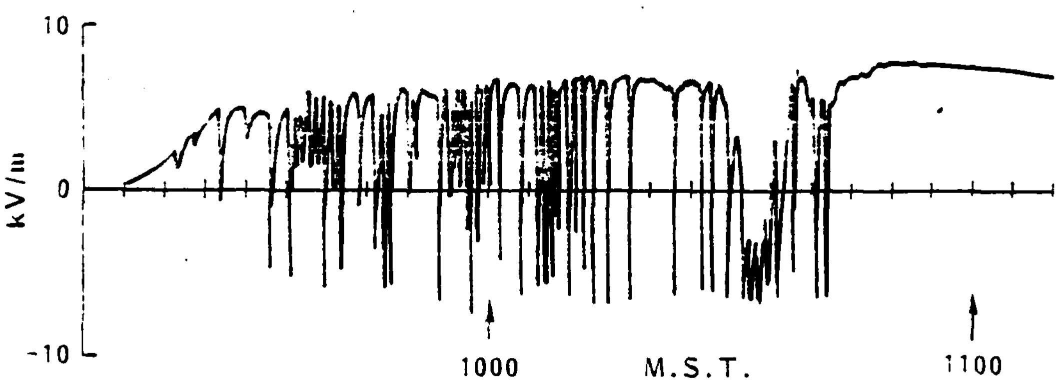
The typical sequence of electric fields observed at the earth's surface beneath a stationary thunderstorm is shown in Fig. 3. With the development of electrification in the cloud, the field polarity reverses from the fine-weather, downwardly-directed sense to the foul-weather, upwardly-directed one. Initially, the foul-weather field increases exponentially in strength, doubling its intensity every 2 min or so. When the field strength exceeds 3 kV/m or so, point discharge commences, causing an electric ion current to flow into the air from conductors exposed to the field. These ions constitute a space charge that opposes the field intensification. Thereafter, the surface field intensities grow more slowly than does the field aloft as more and more ions are emitted. Finally, a surface field strength is reached at which the resulting ion current just balances the increases in field strength aloft. The fields aloft may reach strengths in excess of 150 kV/m and often culminate in production of a lightning flash. The surface fields, however, are usually limited by the space charges in the subcloud layer to values of less than 15 kV/m.

The sharp discontinuities shown in Fig. 3 are the result of lightning transport of negative charge away from the cloud overhead. When the lightning is very near, as in the case shown in Fig. 3, the electric field reverses polarity for a short time after each discharge, briefly showing the effect of the positive-point discharge ions in the subcloud region. The field then rapidly recovers to its predischarge polarity and intensity as the electrification process continues in the thundercloud.

When a growing cloud becomes electrified, its electric field can be detected before the cloud produces its first lightning. In the example of Fig. 3, electrification and first lightning are separated by about 7 min. Typically, a period of 5 min or more will occur between initial



(a) Electric field at solar tower.



(b) Electric field at Langmuir Laboratory.

Figure 3. Electric field recordings at two stations separated by 1.8 km beneath a thundercloud on August 7, 1979. An upward-directed electric field indicates an upward electric force on a positive charge in the field; this is the foul-weather polarity for the field. The discontinuities in the recordings are field changes due to lightning. (Ref. 2, p. 38.)

electrification and first lightning. Some clouds become electrified, with measurable fields on the ground, but the fields in the cloud never grow strong enough to produce lightning. Fields measured on the ground can be used to warn of lightning before it occurs but not without occasional false alarms.

A formed, lightning-producing thunderstorm which blows in from elsewhere will give a longer warning time. As seen from Fig. 2, the ground-level fields will not build strongly in the foul-weather direction until the storm is closer than about 5 km, from which distance it may arrive within a few minutes. Nonetheless, a longer warning can be derived by observing the field changes associated with the storm's lightning.

A typical cloud-to-ground discharge transports 25 C of charge to the ground. At a distance of 10 mi, this produces a field change of 300 V/m; at 20 mi, the field change is 50 V/m. Changes of these magnitudes are easily measured with modern field mills and can be used to give warning of an approaching storm.

3. MECHANISMS OF LIGHTNING DAMAGE

A detailed description of lightning and its origin will not concern us here. (Comprehensive treatments can be found in Refs. 1 and 4.) Only those features of lightning which cause damage to structures, equipment, and personnel are of concern here. The following discussion on the mechanisms of lightning damage is extracted from Reference 2.

A typical peak current in a lightning discharge is 2 to 14 kA, with some discharges having currents exceeding 100 kA. These large currents can produce damage directly, and the large electric and magnetic field changes associated with the currents can cause damage by induction.

3.1 DIRECT STRIKES

Direct lightning strikes can produce damage as a result of the high currents and heating caused by the currents, mechanical effects from the shock wave, and side flashes to nearby objects.

3.1.1 Damage due to lightning current. Lightning currents cause damage by joule heating. If a current of amplitude i is passed through a resistance R, the electrical heat deposited in the resistance will be proportional to the time-integral of the power dissipation, $\int i^2 R dt$. If R is assumed to be independent of current and temperature and the effects of thermal conduction can be neglected, then the temperature rise of a wire will be proportional to the action integral, $\int i^2 dt$. The maximum $\int i^2 dt$ recorded for lightning currents is about 10^7 A^2s.

Calculations of the temperature rise of of varying cross sections of copper conductors are shown in Fig. 4 (Ref. 5). Temperature rises for aluminum and steel conductors are about 1.5 and 10 times larger.

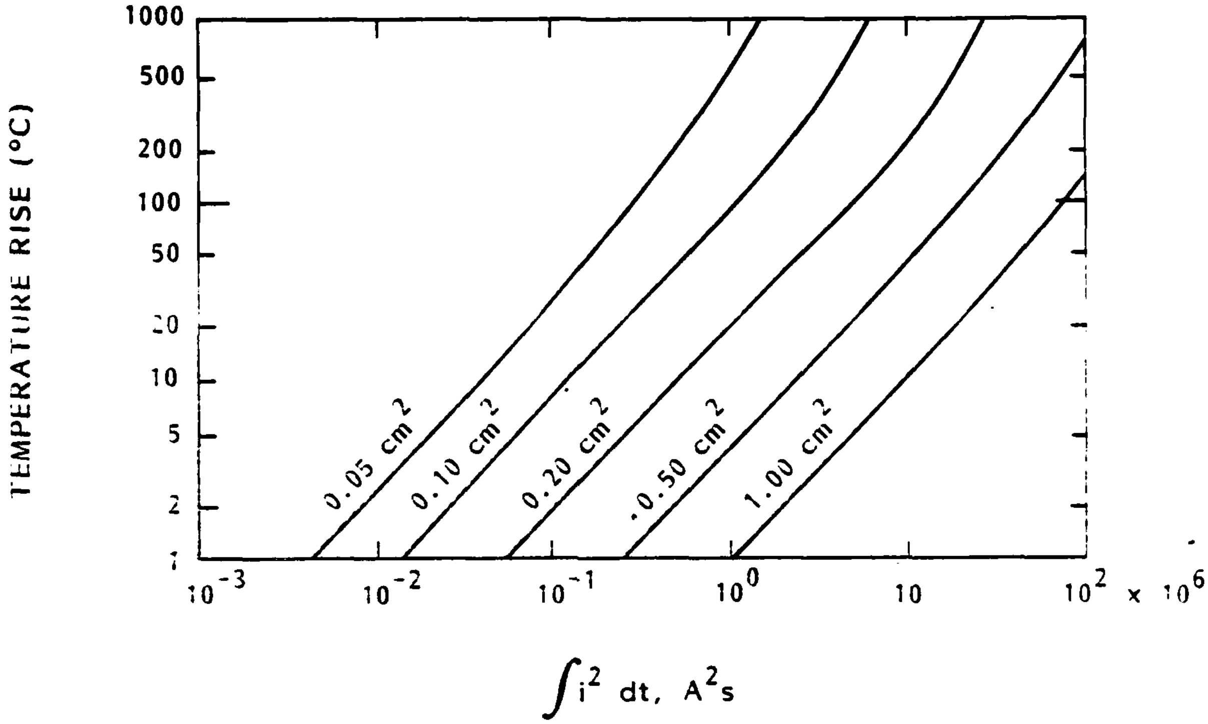


Figure 4. Temperature rise of copper conductors of varying cross sections as a function of $\int i^2 dt$. (Ref. 5, Ch. 5, Fig. 23.)

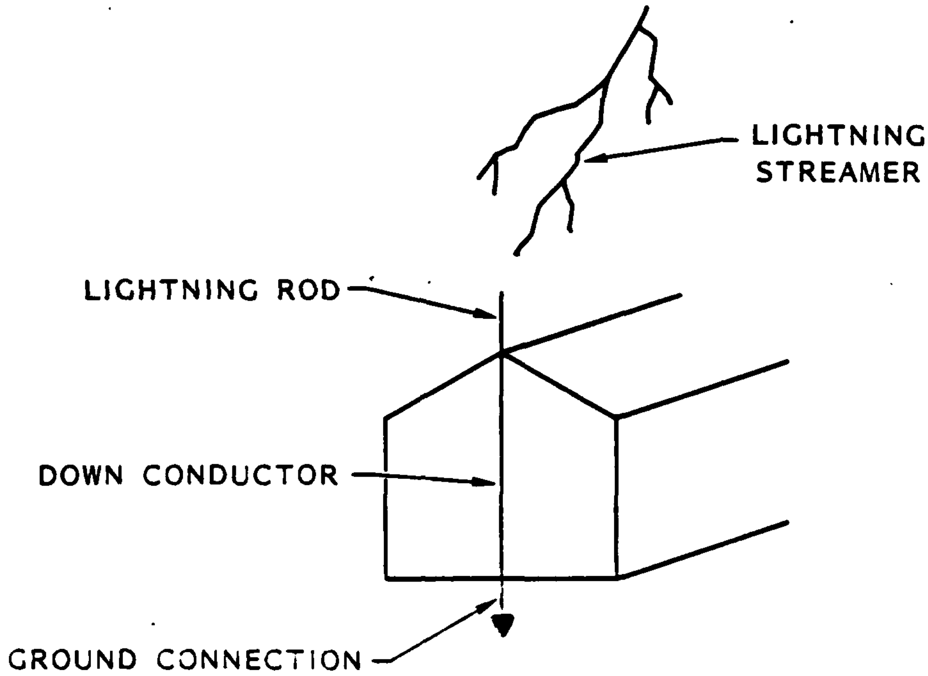
respectively, than those shown in Fig. 4. From these curves it was concluded that even a $\int i^2 dt$ of 10^7 A^2s will raise the temperature of a 56 mm^2 (0.33 in diameter) steel cable by only 150°C, a value which is readily acceptable. Smaller steel cables may not be acceptable because of the larger thermal dissipation. If a metal conductor has a bond or joint with another conductor, it is important there be a good electrical contact or a low resistance between them. A high resistance joint can produce substantial heating and/or sparking and must be avoided.

3.1.2 Damage due to mechanical effects. The shock wave produced by a lightning channel and the magnetic forces due to lightning currents can cause mechanical damage. This should be taken into account when designing lightning protection systems.

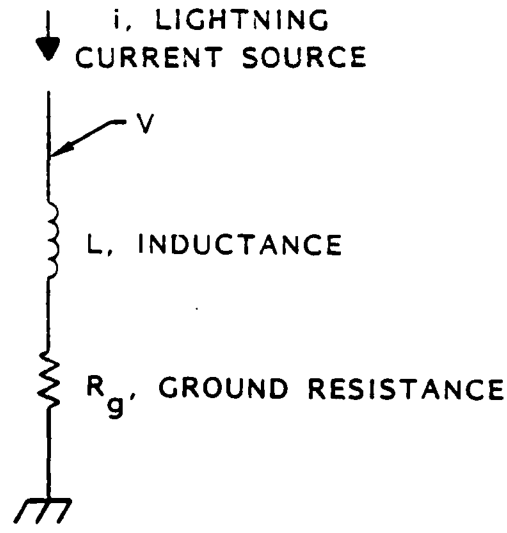
The shock wave is produced by the rapid heating of the channel to temperatures on the order of 30,000 K, which produce channel pressures of up to 30 atm. This produces a strong cylindrical shock wave, which relaxes to a sound wave (thunder) at a distance of a few meters from the channel. The shock wave heats the air nearby and can cause mechanical damage.

When two parallel conductors carry current in the same direction, the magnetic fields produce an attractive force. This force is proportional to the square of the current and inversely proportional to the distance between the conductors. These magnetic forces can crush metal tubes, pull wires from walls, and fuse stranded conductors. The components of a system of lightning conductors should not be placed in close proximity to each other.

3.1.3 The side flash. When a large, rapidly varying current is injected into a lightning conductor (see, for example, Fig. 5), the inductance of the conductor and the resistance of the ground connection



(a) Simple lightning protection system.



(b) Equivalent circuit.

Figure 5. A simple lightning protection system consisting of a single rod, a down conductor, and a ground connection. Also shown is the equivalent circuit for the system. (Ref. 2.)

are often large enough to produce a side flash, i.e., a discharge from the conductor to a nearby grounded object. A side flash occurs when the potential of the conductor is raised to a value large enough and of sufficient duration to initiate a spark and cause it to propagate to the nearby object. Normally, the DC resistance of the wires in a lightning protection system is much less than the inductive impedance or the ground resistance. In the example of Fig. 5, a wire 10 m long with an inductance of 1.5 μH/m, in series with a ground resistance of 10 Ω, will develop a potential of 2 million volts across it for a 40 kA current. This is easily large enough to cause a flashover. One of the biggest hazards of standing near an isolated tall object during a thunderstorm is the exposure to a possible side flash.

3.2 INDUCED EFFECTS

Nearby lightning flashes can cause damage to structures and electronic equipment as a result of the large electric and magnetic field changes and the effects of currents in the ground.

3.2.1 Magnetic induction. If a closed loop of wire or any other closed conducting path is exposed to a time-varying magnetic field, a current will be induced to flow in the circuit. The magnitude of the current is proportional to the time-derivative of the magnetic flux density (magnetic field strength times the area of the closed path) and inversely proportional to the circuit impedance. It is important to avoid large conducting loops which are exposed to the fields of nearby lightning strikes.

3.2.2 Electric induction. Whenever a conductor is exposed to an external electric field, a surface charge proportional to the strength of the electric field is induced on the conductor. If the field varies with time, currents will flow in the conductor to keep the surface charge in balance with the field.

4. THE PERMANENT HIGH EXPLOSIVES TEST SITE

The PHETS site is located on the northern end of the White Sands Missile Range in south-central New Mexico. This region receives an average of 40 to 50 thunderstorms a year, mostly during the summer, according to a 30-yr average of U.S. Weather Bureau records. More important than the number of thunderstorms is the strike frequency. Estimates for strike frequency range from 2 to 6 strikes per square kilometer per year in regions which receive 30 thunderstorms per year. The Bureau of Land Management has recently installed a lightning location system throughout the western United States. We will soon have access to the system and its records and will be able to give a detailed picture of lightning strike frequency and location in the PHETS area. Even without this detailed information, it is obvious that with 2 to 6 strikes per square kilometer per year, the PHETS site will certainly be struck many times during an experiment conducted in the thunderstorm season.

Most of the thunderstorms in the region occur in the summer when there is energy from heat to drive the large instabilities necessary for the storms to grow. However, thunderstorms in the region are not limited to the summer and have been known to occur in every month of the year. Damage to sensors and instrumentation at the PHETS site occurred during preparation for the Direct Course event in the fall of 1983. Lightning is a potential hazard during any season. It is necessary to design a lightning protection system with the assumption that it will be needed several times during an experiment.

5. LIGHTNING PROTECTION SYSTEM

5.1 INTRODUCTION

A lightning protection system can be designed to protect against a direct strike or against induced effects only. Absolute protection against direct strikes requires completely enclosing the area in a metallic enclosure, a Faraday cage. This is clearly impossible for an area the size of PHETS, or for any structure which has power lines, signal lines, plumbing, etc. entering it.

The proposed protection system for PHETS should protect items of high value and/or importance from direct strikes by diverting the current away from the item to the ground and shielding it from any lightning-caused transients. This level of protection should be applied to the high-explosives (HE) charge, the Administration Park, the instrumentation bunkers, regions of closely grouped sensors, etc. Less valuable items, such as cables, isolated sensors, etc., need protection against induced transients only.

Protection of personnel consists of evacuating to safe areas during potentially hazardous conditions. This involves a system to warn of the growth of a thunderstorm, or of the approach of an already developed thunderstorm.

5.2 PROTECTION OF INSTRUMENTATION

The instrumentation system consists of three parts: sensors which produce signals, cables which transmit those signals, and the instrumentation bunkers in which the signals are recorded. The following are some primary considerations when designing a lightning protection scheme for such a system. Conducting loops must be avoided since magnetic induction will cause currents to flow through such loops. If possible, all parts of the system should be kept at the same potential so that there are no potential differences which could cause arcing. In practice this is nearly impossible except with the use of a perfect Faraday cage. Our goal is to minimize the potential differences and, in places where lightning potential differences can occur, to utilize voltage limiting devices to hold or clamp these transients to a harmless level.

The instrumentation bunkers, as currently designed, are well protected from direct lightning strikes. A buried bunker, enclosed in metal except for a few small openings, is a good Faraday cage. Power supplied by a nearby diesel generator should result in little degradation. The power lines should be buried and, upon entering the instrumentation bunker, be conditioned with lightning arrestors and radio frequency interference (RFI) filters. Putting the diesel generator in a similar bunker, or burying it, would be useful. If power is supplied over commercial power lines, isolating the bunker power with isolation transformers and motor generators will be necessary.

All conductive loops must be avoided. Several examples of proper and improper ways of connecting sensors to the instrumentation bunkers through cables are shown in Fig. 6. As well as avoiding loops between the bunkers and sensors, loops must be avoided among the bunkers, between bunkers and the Administration Park, Timing and Fire Park, etc. Communications should be carried out by radio and fiber-optics links. (The fiber optics cables should, of course, be nonconducting.) An instrumentation bunker and its set of sensors should be considered a single unit with no conducting connections between different units. (Ideally, the Administration and Timing and Fire Parks, etc. should also be thought of as separate units with no conducting interconnections. This may be difficult to implement, however.)

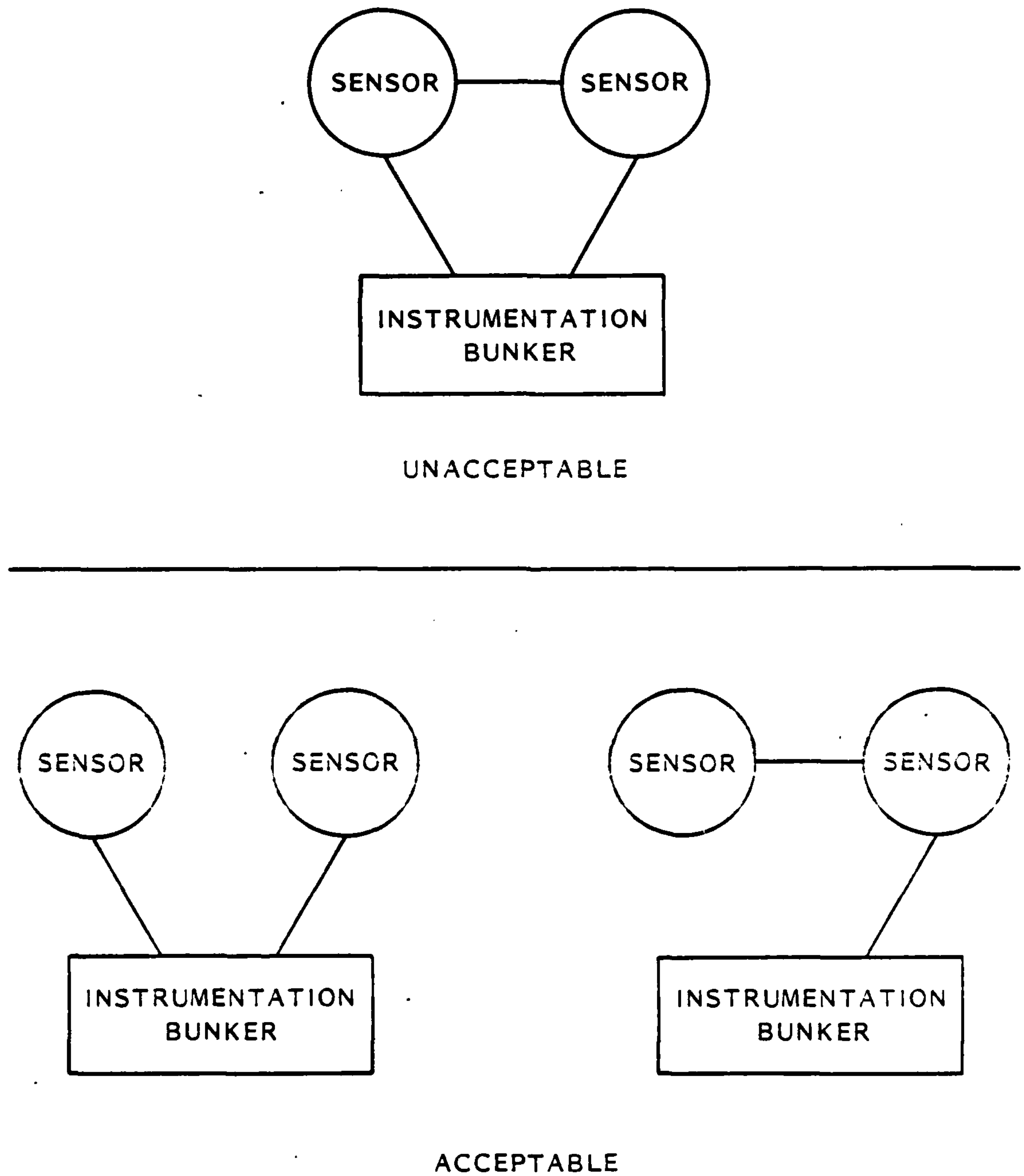


Figure 5. Sketch of acceptable and unacceptable connections for avoiding loops between sensors and instrumentation bunkers.

The next item to consider is transients caused by electrical potential differences. Ideally, all parts of a unit would be kept at the same potential by enclosing them in a Faraday cage. This may be possible for a few sensors of high importance; other sensors can be protected by proper grounding, isolation, and transient protection. In a unit, a single reference potential, or ground, must be established. The most convenient ground is the metal structure enclosing the instrumentation bunker. This is the only point in the unit where ground rods should be used. Ground rods should not be used at the sensor end of a cable unless the sensor ground is isolated through resistors or amplifiers as discussed in the following sections.

5.2.1 High importance sensors. Sensors of high importance can be protected by enclosing them and their connecting cables in metal. Power and signal lines can be run between the sensor and instrumentation bunker via metal conduit. The sensor will ideally be enclosed in metal, with a small opening to the outside world to make its measurement. Cables to other sensors can be branched off. However, all loops must still be avoided, and ground rods should not be used at the sensors. Figure 7 shows such a scheme.

5.2.2 Lower importance sensors. For sensors where a Faraday cage is economically impractical, isolation techniques must be employed. As discussed previously, the key idea here is that there must be only one ground in a unit, and that ground should be the metal shield enclosing the instrumentation bunker.

Isolation can be achieved by disconnecting cables at both the sensor and the instrumentation bunker ends. However, this should be unnecessary since experience gained at Langmuir has shown that, with proper isolation and transient protection, cables in a system can remain connected during

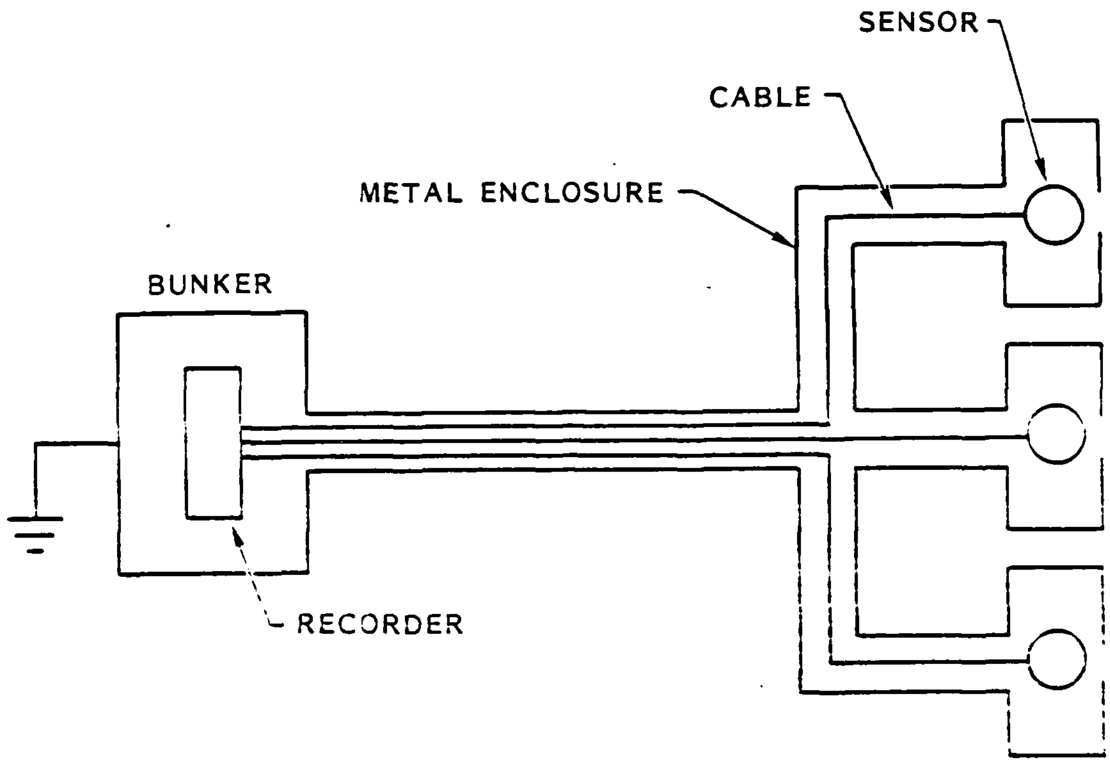


Figure 7. Recommended method of connecting high importance sensors to instrumentation bunkers by shielding in metal enclosure.

a thunderstorm with little fear of damage. Each disconnection and reconnection can result in a damaged connector and a (possibly undetected) bad connection. It may not always be possible to disconnect if a storm builds quickly. Someone may forget to reconnect a cable after a storm, resulting in lost data from the sensors served by that cable. The following recommendations are made for disconnecting cables if it is decided that disconnecting them is the best way to protect the instrumentation.

After disconnecting a cable, there will be three separate, unconnected units: the instrumentation bunker, the cable, and the sensor. Each should have its own connection to ground. The instrumentation bunker is already grounded. All that needs to be done is to put a metal blank-off cap over the (now unoccupied) cable input. The cable should be grounded at one end only -- the end at the instrumentation bunker seems easiest. A shorting cap connecting the sheath and all conductors should be put on and should be attached to ground (i.e., a ground rod). A shorting cap should also be put on the other end of the cable and connected to ground through a resistor. In this way, if high potentials develop in the cable, a limited current can flow through the resistor to ground, limiting arcing between the cable and ground. The sensor should be protected with transient protection devices as discussed below and grounded at a point as near the sensor as possible.

Whether or not cables are disconnected, transient protection devices should be put on both at the sensor and at the instrumentation bunker. Isolation of grounds through the use of isolation amplifiers or differential amplifiers should be accomplished where possible. Three schemes are presented for connecting sensors to recorders: using only passive elements for ground isolation, using differential amplifiers, and using isolation amplifiers. Any of these could be produced in small packages and provided to the experimenters. Note that in these schemes there is a ground at the sensor which is isolated from the ground at the instrumentation bunker.

Figure 8 shows transient protection and isolation using transient suppression devices and RFI filters only. Two transient suppression devices are shown -- a spark gap (typically NE-98 neon lamps) and TransZorbs (fast-clamping zener diodes manufactured by General Semiconductor). The TransZorbs clamp quickly (in less than 1 ns) but cannot carry large currents. The spark gaps switch from a very high impedance state to a short circuit state. They do not absorb much energy, but instead reflect it away form the short circuit. These elements have been used successfully at Langmuir. Other transient protection devices are available, such as metal oxide varistors (MOVs) and Surgectors (a combination zener diode and thyristor, manufactured by RCA). Studies should be made to determine how to best achieve a combination of fast-clamping and high-energy dissipation.

Differential amplifiers can be used to shift reference grounds to prevent ground loops. Figure 9 shows a representative circuit.

A higher degree of isolation can be obtained by use of isolation amplifiers. These work on the principle of converting an analog voltage to a frequency, transmitting the frequency across a transformer or optocoupler, and converting the frequency back into an analog voltage. These have a lower bandwidth than the other methods; typical commercial isolation amplifiers have bandwidths of 1 to 20 kHz. If this lower bandwidth is acceptable, isolation amplifiers provide a much higher degree of protection. Figure 10 shows a representative circuit.

Cables can be protected by using a neutral overhead copper wire, located above the cable and grounded at regular intervals (every 100 ft

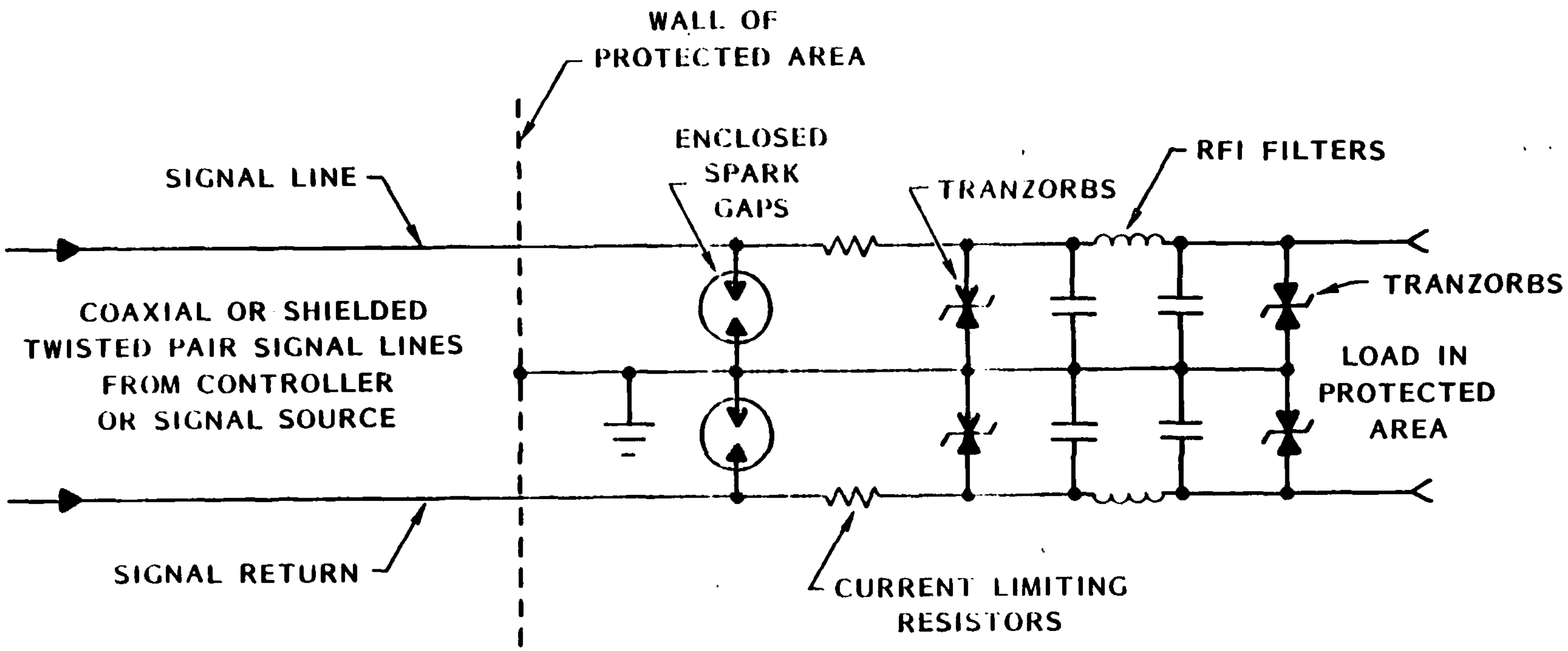


Figure 8. Recommended transient suppression of signals leaving sensors or entering instrumentation bunkers.

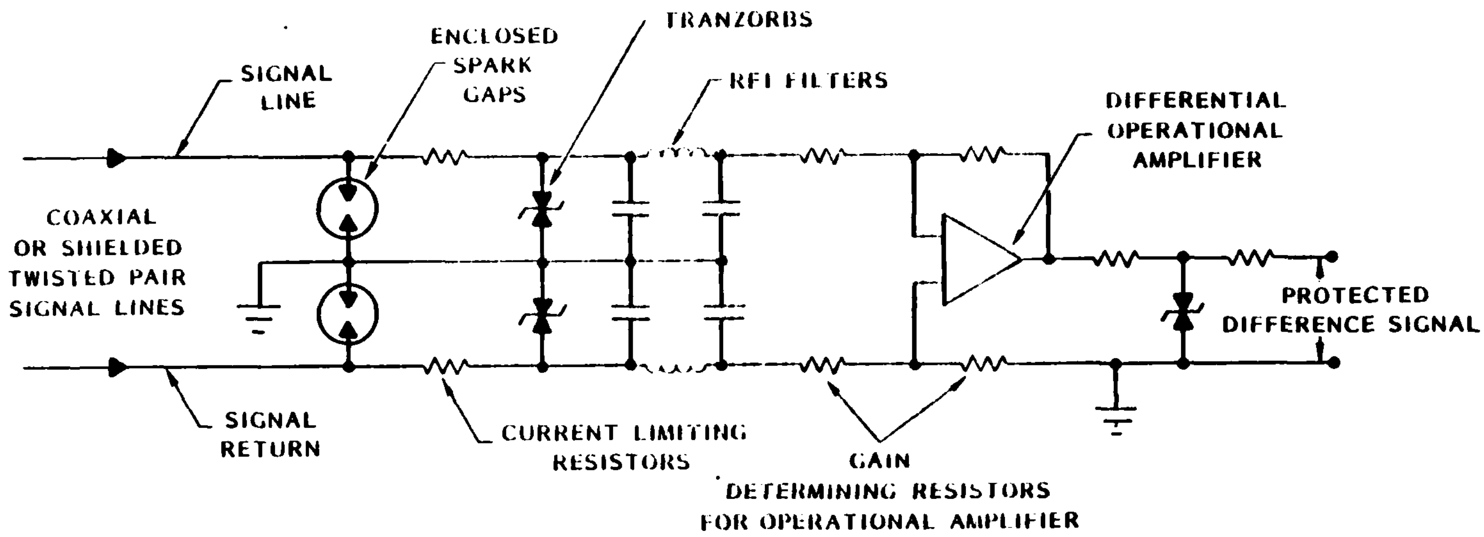


Figure 9. Recommended use of a differential amplifier to shift reference grounds and to avoid transient impacts by ground loops.

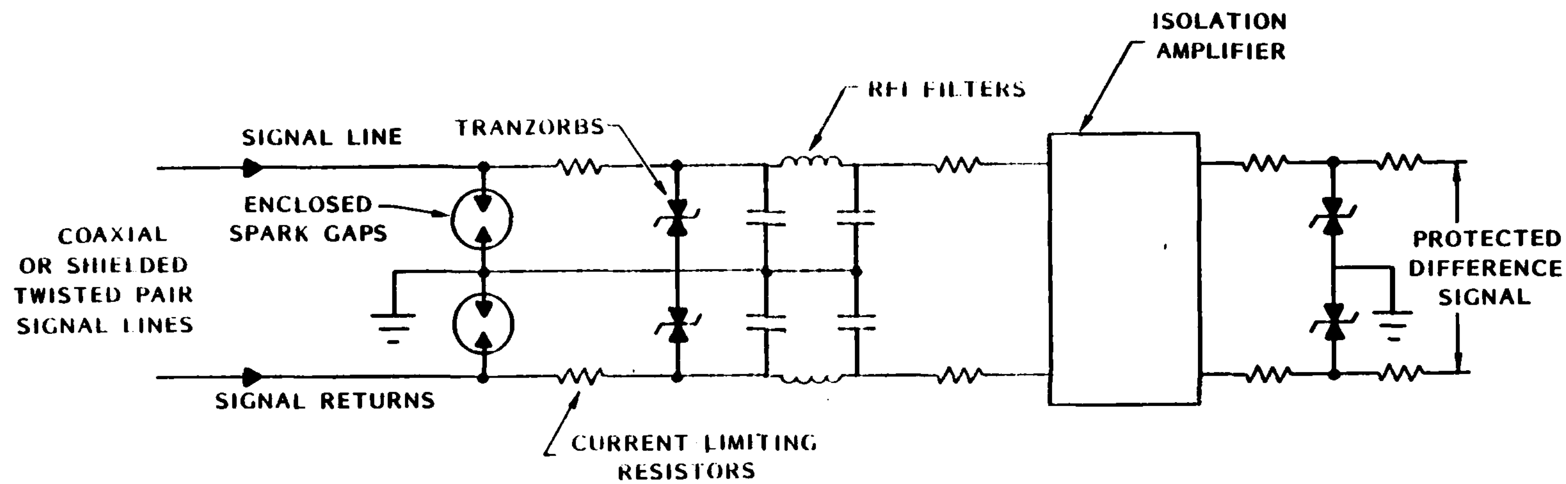


Figure 10. Recommended use of an isolation amplifier to shift reference grounds and to avoid transient impacts by ground loops.

or so). The current from lightning tries to find the least resistive path to the ground. The cable, with its low conductivity wires, provides an attractive path for the current. A heavy copper wire located above the cable presents an even less resistive path. The current will disperse itself along the copper wire rather than the cable, thereby protecting the cable. Grounding the overhead neutral wire at regular intervals gives the lightning current paths to disperse into the ground. If a cable is buried 5 to 6 ft underground, the overhead neutral is best buried above the cable a few feet below ground level. However, the overhead neutral technique is very useful even if the neutral is not buried. If a cable is lying in an open trench, placing the overhead neutral on the ground at the edge of the trench is an effective way of diverting lightning currents from the cable.

5.3 PROTECTION OF THE HIGH EXPLOSIVE

The easiest way to adequately protect the HE is probably a maypole arrangement, as illustrated in Fig. 11. The conical array of down-conducting guy wires minimize the problem of side flashes to the HE. The guy wires should be at least 56 mm^2 in cross section to avoid unacceptably high temperature rises, as discussed in Section 3. Larger guy wires may be necessary for structural strength. In constructing the maypole, it is important to use gentle bends where bends are necessary. Sharp bends in down-conductors increase the conductor's local impedance which can increase local potential differences and produce side flashes. All changes in direction of a down-conductor should be made gently, with the radii of curvature always exceeding 25 cm (8 in).

Any cables leading into the HE charge are a potential source of induced effects. Such cables should be well shielded, and the shield should be grounded outside, but close to, the charge container. The sensors inside the charge container should be protected with transient protectors as discussed above.

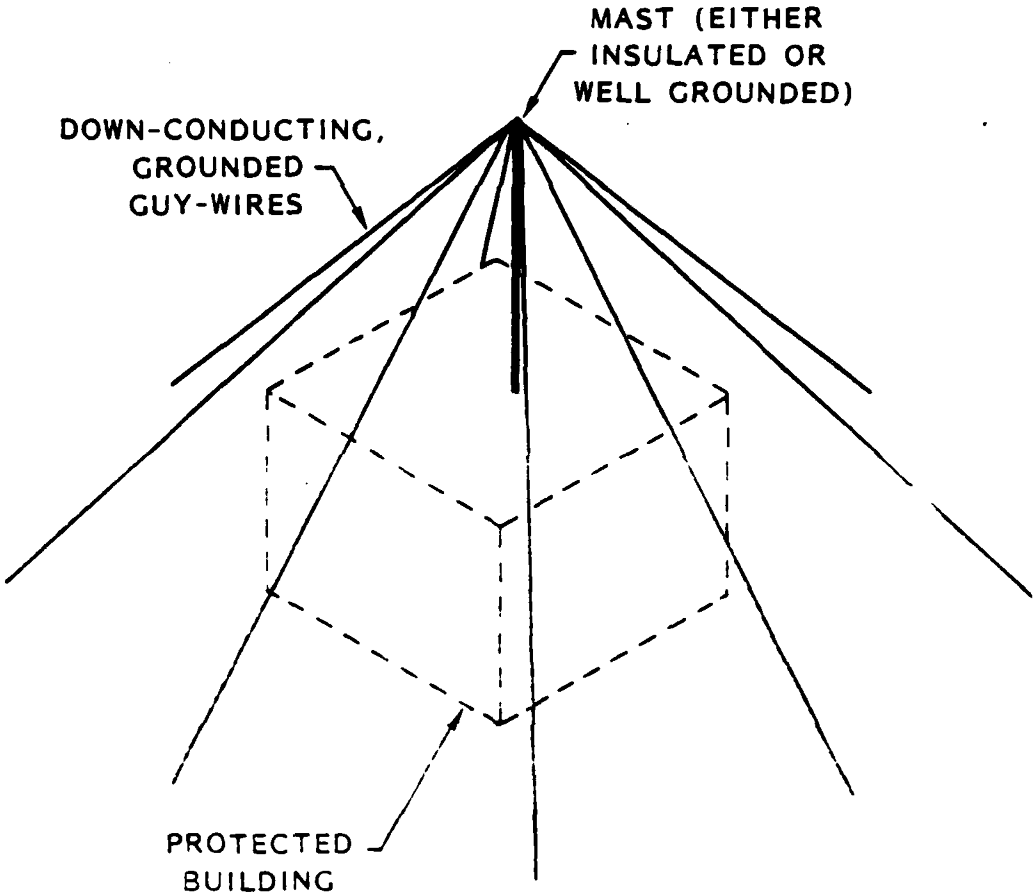


Figure 11. Proposed may[illegible] lightning protection concept. The concept uses a mast over the structure to be protected and a conical array of down-conducting guy wires. (Ref. 2, p. 79.)

5.4 PROTECTION OF PERSONNEL

Hazards to personnel consist of a direct or nearby lightning strike, falling debris, and explosions set off by lightning. During storms, the approach of storms, and the growth of storms, personnel should be evacuated to safe areas, such as inside buildings or to vehicles situated away from areas subject to damage by explosion or falling debris.

Section 2 discussed the precursors to an approaching or growing thunderstorm which can be used to predict a lightning hazard. Department of Defense regulations require suspension of work with explosives during potentially hazardous conditions. The following is extracted from NAVSEA OP 5, Volume 1:

> 4-9.1.2: Storm Warning Systems. . . . . . When the ground level electric field exceeds 2000 V/m, it is an indication that there is an increasing probability of lightning at the ground level. All operations involving EEDs or open powders and explosives should cease when the earth's electric field exceeds 2000 V/m. During extremely dry weather, such as the winter, the electric field strength may exceed 200 V/m without lightning activity. During this time static electricity is generally the greater danger but the hazard of lightning can also exist. The hazards to operations under these conditions **must be evaluated on a case-by-case basis.**
>
> **4-10 OPERATIONS DURING ELECTRICAL STORMS**
>
> **Each activity shall establish a specific documented criteria for terminating ammunition and explosive operations at the approach of a thunderstorm. This criteria shall be based** on the sensitivity of the operation involved and the amount of

time required to safely terminate the operation. In no case shall a storm approach closer than 5 miles without termination of an ordnance operation.

A system capable of measuring ground-level electric fields and detecting nearby lightning discharges is necessary for implementation of these regulations. Electric field mills and lightning location systems provide these capabilities.

Cardiopulmonary resuscitation has been effective in reviving people whose hearts have stopped as a result of lightning and other electrical shocks. The lightning protection standards should emphasize the procedure, safety seminars demonstrating it should be held, lead personnel and others should be indoctrinated in it, and posters illustrating the technique should be prominently displayed.

5.4.1 Electric field mill. An electric field mill is a device to measure the ground-level electric field. The fields of a typical thunderstorm recorded on an electric field mill are shown in Fig. 3. This storm grew in place over Langmuir Laboratory. The electric field increased in the positive direction, with lightning discharges occurring after the field reached 3 kV/m. Lightning continued with discharges occurring several times per minute until the storm dissipated after about an hour.

An electric field mill will not measure the fields of an approaching thunderstorm until the storm has nearly arrived. It will, nonetheless, record the strong field changes produced by lightning discharges in the storm while the storm is tens of miles away. This capability allows the mill to be used to warn of approaching storms.

A minimum of two field mills should be used for PHETS, one located at ground zero and the other at Administration Park. Other mills could be installed at outlying locations if desired, and a spare mill should be available as a backup. The mills should be connected to an automatic recording device and an alarm system at a location where they could easily be monitored, such as Administration Park. The recording device need not generate a continuous record of the fields, such as a simple chart recorder would. The fields should be monitored and recorded by a microcomputer or similar device. When the fields reach a preset level, the microcomputer would issue an alarm and display the immediate history of the fields for interpretation. The microcomputer would also process the field signals to look for fast changes indicating distant lightning discharges and would issue an alarm and give an approximate distance to such discharges.

The alarm for the mills should be set at a level that will warn responsible personnel of an impending hazard before it becomes necessary to evacuate the test-bed. A local field of about 1000 V/m, or field changes indicative of lightning activity anywhere in the region, should activate a preliminary alarm. A general alarm which could be overridden should be sent when local fields reach 2000 V/m or lightning is within 5 mi. In this way, trained personnel can make an informed decision based on observations of current conditions as to whether evacuation is required. A general alarm need not be sent, for example, during a clear, dry day when blowing dust creates strong fields near the mills. At times when trained personnel are not available to respond quickly and override the general alarm, the evacuation order would be sent automatically when conditions reached prescribed levels.

Before the high explosive is loaded, evacuation of the test-bed will not be necessary for lightning hazards. Personnel should seek shelter in safe areas, such as buildings, instrumentation bunkers, and vehicles. Vehicles should be moved to areas away from power lines and overhead wires and structures which could fall if hit by a direct strike. All work with explosives, such as those used for weather tests, should, of course, cease.

After loading of the charge begins, personnel should be evacuated from the test-bed and the amonium nitrate fuel oil loading area. A safe distance will depend on the size of the charge and must be decided upon by Defense Nuclear Agency (DNA) personnel. Access to the test-bed should not be allowed until the person responsible for monitoring the fields determines that the hazard is past.

5.4.2 Lightning location system. As a supplement to the electric field mills described in the previous section, additional warning could be provided by gaining access to an existing lightning location system. The Bureau of Land Management operates an Automatic Lightning Detection System (ALDS) designed to determine locations of possible lightning-initiated wildfires. This system can locate cloud-to-ground discharges over 95% of the eleven western states, including the White Sands Missile Range region. Beginning in the spring of 1986, New Mexico Tech will have access to the data from this system, as detailed in the Appendix. DNA could install a dedicated line between New Mexico Tech and PHETS, giving DNA real-time information on lightning location. This information could be displayed graphically, giving an up-to-the-minute picture of thunderstorm activity and movement in New Mexico. The information could also be used to alert personnel when a thunderstorm is within a prescribed distance of PHETS. This system cannot detect the in situ growth of a thunderstorm and does not obviate the need for field mills. It would, however, provide additional valuable information on current conditions to aid in making the decision to cease operations.

6. SUMMARY OF RECOMMENDATIONS

For lightning protection at PHETS, the following recommendations are made.

1. Protect the HE charge by means of a maypole arrangement of down-conducting guy wires.

2. Protect the instrumentation bunkers by enclosing them in metal. Power lines should have lightning arrestors installed. If power is provided over long power lines, the bunker should be isolated by isolation transformers and motor generators.

3. Avoid all conductive loops. Treat each instrumentation bunker and its sensors as an isolated unit, with no conductive paths to any other unit. Conductive loops within a unit should also be avoided.

4. Protect sensors and recorders with transient overflow devices and ground-level shifters.

5. Protect cables by use of overhead neutrals.

6. Provide warnings of lightning hazards by monitoring ground-level electric fields and, possibly, the Bureau of Land Management lightning location system.

7. Train personnel in cardiopulmonary resuscitation techniques.

REFERENCES

1. Golde, R.H., ed., Lightning, Academic Press, New York, 1977.

2. Moore, C.B., M. Brook, and E.P. Krider, A Study of Lightning Protection Systems, report to the Atmospheric Science Program of the Office of Naval Research, 1981.

3. Morrison, R., Grounding and Shielding Techniques in Instrumentation, John Wiley, New York, 1967.

4. Uman, M.A., Lightning, Dover Publications, New York, 1984.

5. Golde, R.H., Lightning Protection, Chemical Publishing Company, Inc., New York, 1975.

APPENDIX

MEMORANDUM OF UNDERSTANDING
BETWEEN
THE BUREAU OF LAND MANAGEMENT
AND
NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY

INTRODUCTION

A. The Bureau of Land Management owns, operates, and maintains an Automatic Lightning Detection System (ALDS) which provides information on cloud to ground lightning discharges for about 95% of the land area of the Eleven Western United States. The designed purpose of ALDS is to provide a lightning strike data input into the Bureau's Initial Attack Management System (IAMS) which is used for the efficient suppression of wildfires.

B. The New Mexico Institute of Mining & Technology has a need for lightning strike data from the ALDS for research applications.

PURPOSE

This Memorandum of Understanding (MOU) establishes a means whereby the New Mexico Institute of Mining & Technology can obtain lightning strike data from the Bureau of Land Management, Boise Interagency Fire Center in exchange for a suitable location for the BLM's Socorro Direction Finder.

RESPONSIBILITIES

A. The Bureau of Land Management will:

1. Provide the sensor, and data communications link to the Boise Interagency Fire Center.

2. Be responsible for the fire season maintenance of the sensor and data communications link.

3. Provide construction materials, cabling, and manpower as needed for installation of the sensor.

B. The New Mexico Institute of Mining & Technology will:

1. Provide the BLM with a suitable Direction Finder location that is accessible to power, and telephone service.

2. Provide a minimum of 15 watts of 110 volt A.C. Power

for the operation of the direction finder.

3. Providé space and power to locate and operate a 1200 baud modem.

TERMS AND ADMINISTRATIVE PROVISIONS

A. This MOU becomes effective upon signature by the President, New Mexico Institute of Mining & Technology, and the Director, Boise Interagency Fire Center. It shall continue in effect indefinitely unless terminated by mutual consent or upon written notice at least 30 days in advance by one party to the other.

B. Changes to the MOU will be made by negotiation and agreed upon by each party in writing. In the event that anything in the MOU is or becomes in conflict with the direction of higher headquarters authority, the cognizant party shall immediately notify the other party and initiate action to amend the MOU. Neither party shall change equipment or operating procedures without consultation with written notice to the other party.

APPROVAL

The undersigned approve this Memorandum of Understanding and agree to follow the provisions outlined therein.

1/30/86		1/22/8	
Laurence Lattman President New Mexico Tech. Socorro, NM 87801	Date	Jack Wilson Acting Director BLM, BIFC 3905 Vista Ave. Boise, ID 83705	Date

END

12-86

DTIC